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An investigation of the change in resistance of a destroyer type hull utilizing a hydrofoil to reduce excessive trim

Nelson, Perry W.; Greene, John L.

Webb Institute of Naval Architecture

AN INVESTIGATION OF THE CHANGE IN RESISTANCE OF A DESTROYER TYPE HULL UTILIZING A HYDROFOIL TO REDUCE EXCESSIVE TRIM

Perry W. Nelson
and
John L. Greene

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BY

LT. PERRY W. NELSON, USN
AND
LT. JOHN L. GREENE, USN

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ABSTRACT

The basic thinking on which the test was conceived is briefly stated and the proposed procedure is outlined. The detailed steps of the procedure are given presenting the difficulty encountered because the hydrofoil was operating at such a low Reynolds Number. The second approach to the problem which eliminates the effect of low Reynolds Number is outlined and detailed steps are given. The final comparison of results is presented as a plot of © vs $V/\sqrt{L}$.

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INTRODUCTION

At high speeds ships show a marked tendency to "squat". This characteristic of the bow rising and the stern settling, resulting in a comparatively large change in trim, is often thought to be the cause of excessive resistance above the speed length ratio of 1.2. This tendency to squat is very apparent in the destroyer type hull, with a corresponding marked increase of total resistance. It is known that there is an increase of resistance due to increased wave making as the ship's speed length ratio goes above 1.2, but it is felt that the total increase of resistance is the result of both wave making and the change in trim.

It is the purpose of this thesis to determine the resulting increase of resistance, if any, due to the change in trim on a destroyer type hull and further to attempt to reduce or eliminate this increased resistance by use of a hydrofoil under the stern. The purpose of the hydrofoil is to produce a lifting force at the stern to eliminate as much as possible the "squat" at high speed length ratios.

The installation of a hydrofoil with its supporting strut is an additional appendage and thus will increase total hull resistance. This increased resistance must be less than the reduction in resistance resulting from the corresponding change in trim (reduction of "squat") produced by the hydrofoil in order to make the hydrofoil installation profitable. It is our intention to make this comparison through model tests.

PROCEDURE

I. DETERMINATION OF CHANGE IN RESISTANCE DUE TO CHANGE IN TRIM.

A model of a destroyer type hull (see appendix for characteristics) was chosen as a representative destroyer hull form to be used. This model was tested over the speed length ratio from .70 to 1.95 in a bare hull condition and the results are plotted in Figure 11.

In order to determine the effect on resistance of reducing the trim by a lifting force at the stern, the model was run utilizing a system of a pulley and weights attached to the stern as shown in Figure 14. The weights could be varied to simulate various lifting forces that would be produced by a hydrofoil installation. The model with the simulated lift apparatus was run at various speeds ranging from 4.5 feet per second to 7 feet per second, and with various lifting forces. The results of these runs are shown in Figure 1.

The results of this series of model tests show that there is a definite reduction in total resistance of the model due to a reduction in trim. The results further show that the optimum lift desired to obtain minimum resistance is approximately 1.5 pounds. The position of the point of application of the lifting force was 5.00 inches forward of the after perpendicular.

Since the results of the first series of tests showed a definite reduction in resistance under reduced trim conditions and was of the order of 13 to 18 percent of the total resistance of the bare hull, further investigation is warranted.

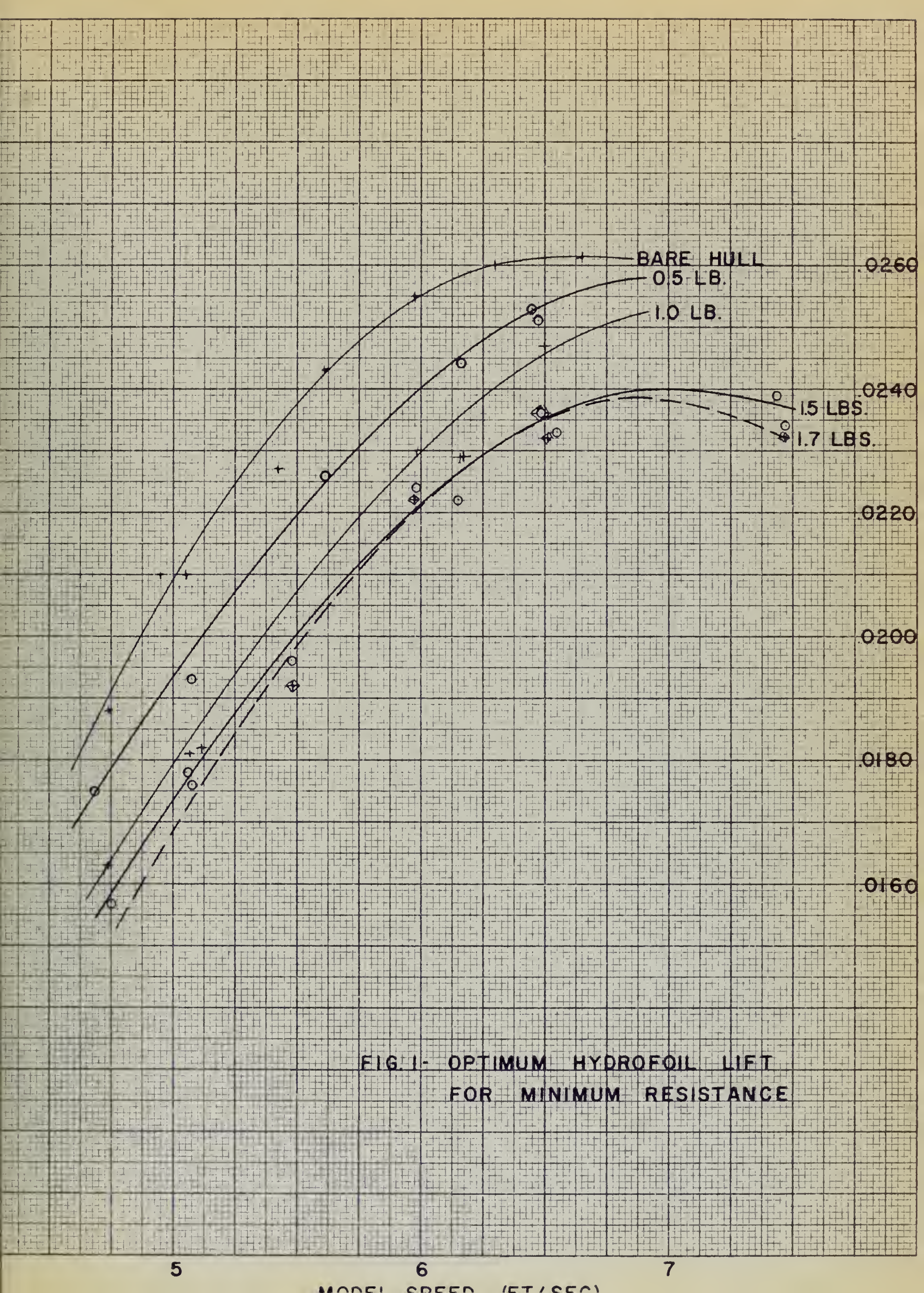


FIG. 1- OPTIMUM HYDROFOIL LIFT FOR MINIMUM RESISTANCE

II. DETERMINATION OF AIRFOIL SECTION AND SIZE OF HYDROFOIL

An airfoil section NACA 63210 from reference (1) was selected on the basis of a high lift to drag ratio. The span of the hydrofoil was determined on the basis that the hydrofoil should not extend beyond the beam of the ship. This dimension for the span was 6.00 inches.

The chordal length was determined by calculating the area necessary for a lift of 1.5 pounds assuming an angle of attack of 6 degrees and a coefficient of lift of .80 based on NACA data from reference (1). The chordal length as calculated was 1.41 inches.

III. DETERMINATION OF OPTIMUM ANGLE OF ATTACK

In order to determine the optimum angle of attack an attachment shown in Figures 2 and 3 was constructed. By use of this attachment it was possible to vary the position of the hydrofoil fore and aft on the model, vary the depth under the hull of the hydrofoil and the angle of attack of the hydrofoil. It was first thought that this attachment could be utilized to determine not only the optimum angle of attack but also the optimum position of the hydrofoil. Actual testing showed that the side struts used to hold the hydrofoil in place had too much resistance and were making all but the determination of the optimum angle of attack impossible due to their high drag.

Figure 4 shows the results of the determination of the optimum angle of attack for various positions of the hydrofoil fore and aft and vertically on the model. In order to maintain

FIG. 2- ADJUSTABLE ANGLE OF ATTACK ATTACHMENT IN FORWARD POSITION WITH HYDROFOIL IN UPPER POSITION AND ANGLE OF ATTACK = 6^{o}.

FIG. 3- ADJUSTABLE ANGLE OF ATTACK ATTACHMENT IN AFTER POSITION WITH HYDROFOIL IN LOWER POSITION AND ANGLE OF ATTACK = 0^{o}.

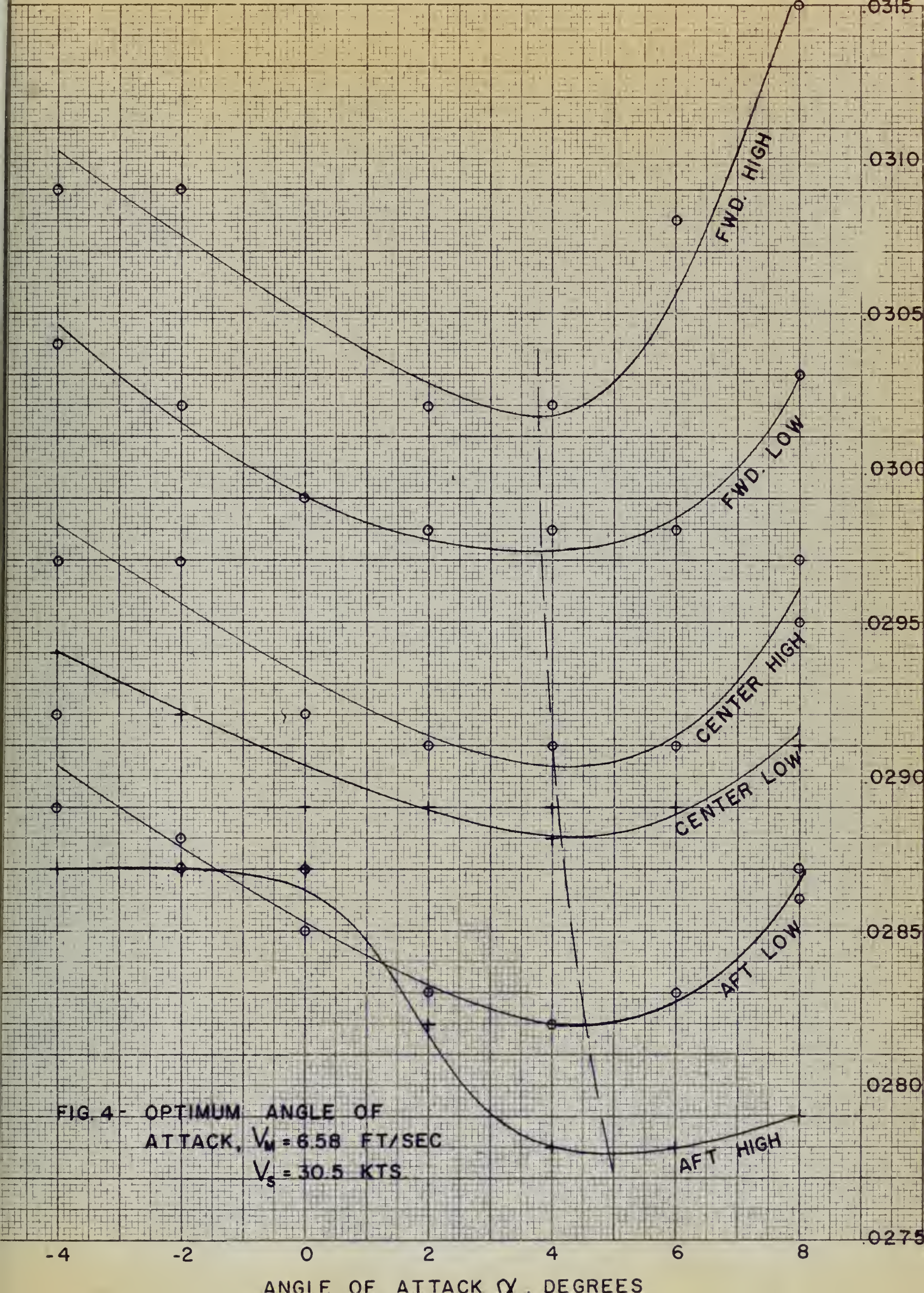


FIG. 4 - OPTIMUM ANGLE OF ATTACK, V_M = 6.58 FT/SEC
V_S = 30.5 KTS.

FIG. 5- HYDROFOIL IN FORWARD HIGH POSITION.

FIG. 6- HYDROFOIL IN MIDDLE CENTER POSITION.

FIG. 7- HYDROFOIL IN AFTER LOW POSITION.

results indicate that the aft low position of the hydrofoil will give the minimum total resistance of the hull. In order to present the effect of the hydrofoil alone the resistance of the strut was subtracted from the total resistance. The value of the strut resistance was obtained by running the model with just the strut attached with the bottom faired with modeling clay. This was done because the primary appendage drag will be caused by the hydrofoil itself due to its induced drag. Results of this test are plotted in Figure 8.

V . DETERMINATION OF MODEL RESISTANCE AND TRIM WITH HYDROFOIL IN FINAL SELECTED POSITION

The model with the hydrofoil in its final aft low position with an angle of attack of 5 degrees as shown in Figures 7, 9, and 10 was tested over the range of speed length ratios from .70 to 1.95.

The results of this set of resistance tests were plotted as C_T vs speed length ratio and are shown in Figure 11. Calculations were made in accordance with proceedures outlined in reference (4). The trims obtained with the hydrofoil attached are shown in Figure 12.

The results of this series of tests showed that the appendage resistance was apparently much greater than the reduction in the resistance due to the controlling of the trim. This would indicate that the total resistance of the model with the hydrofoil installed was much greater than the total resistance of the bare hull model.

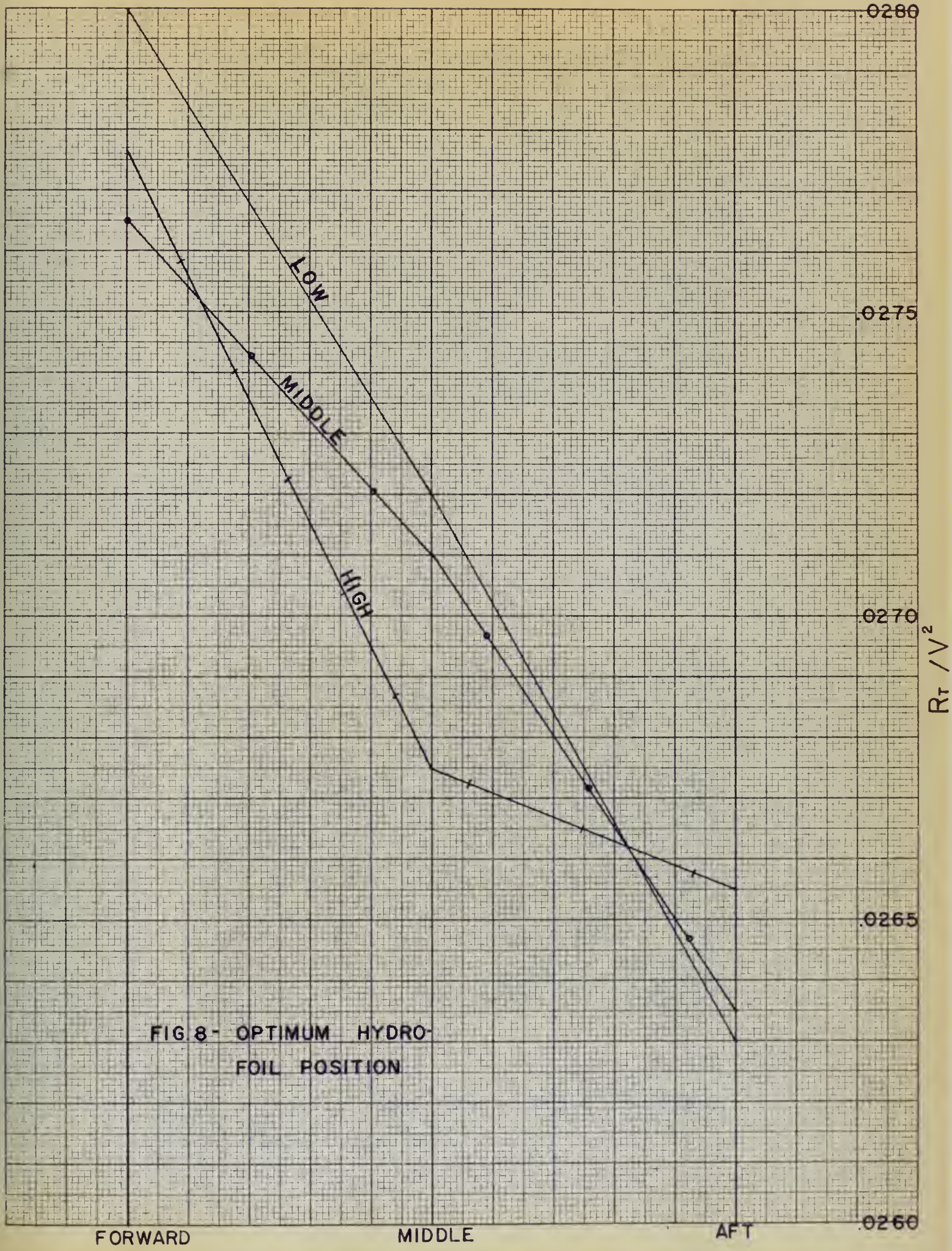


FIG 8 - OPTIMUM HYDROFOIL POSITION

FIG. 9 - HYDROFOIL IN FINAL TEST POSITION.

FIG. 10 - MODEL TEST SETUP WITH HYDROFOIL IN FINAL TEST POSITION.

FIG. 11

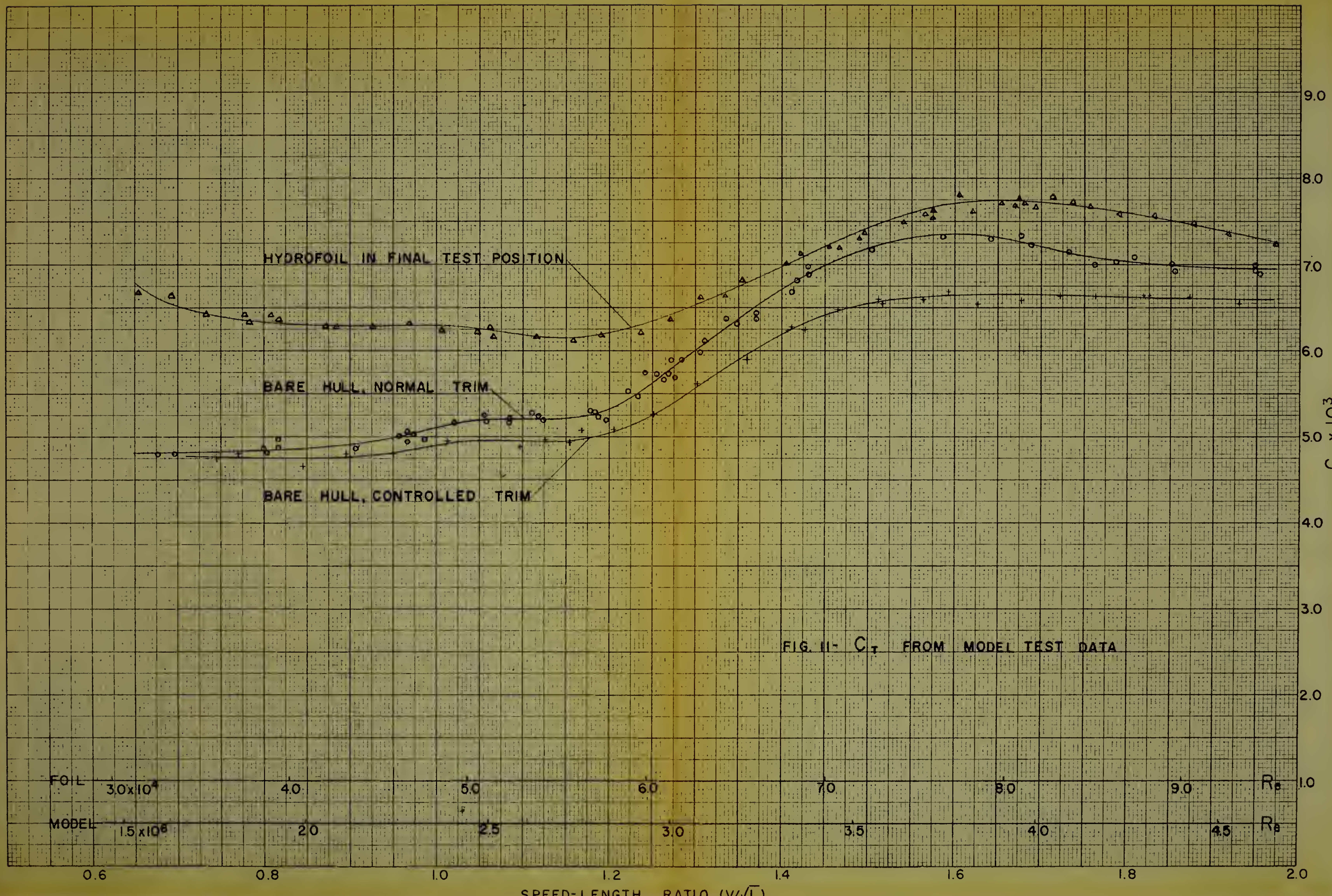


FIG. 11- C_T FROM MODEL TEST DATA

FIG. 12

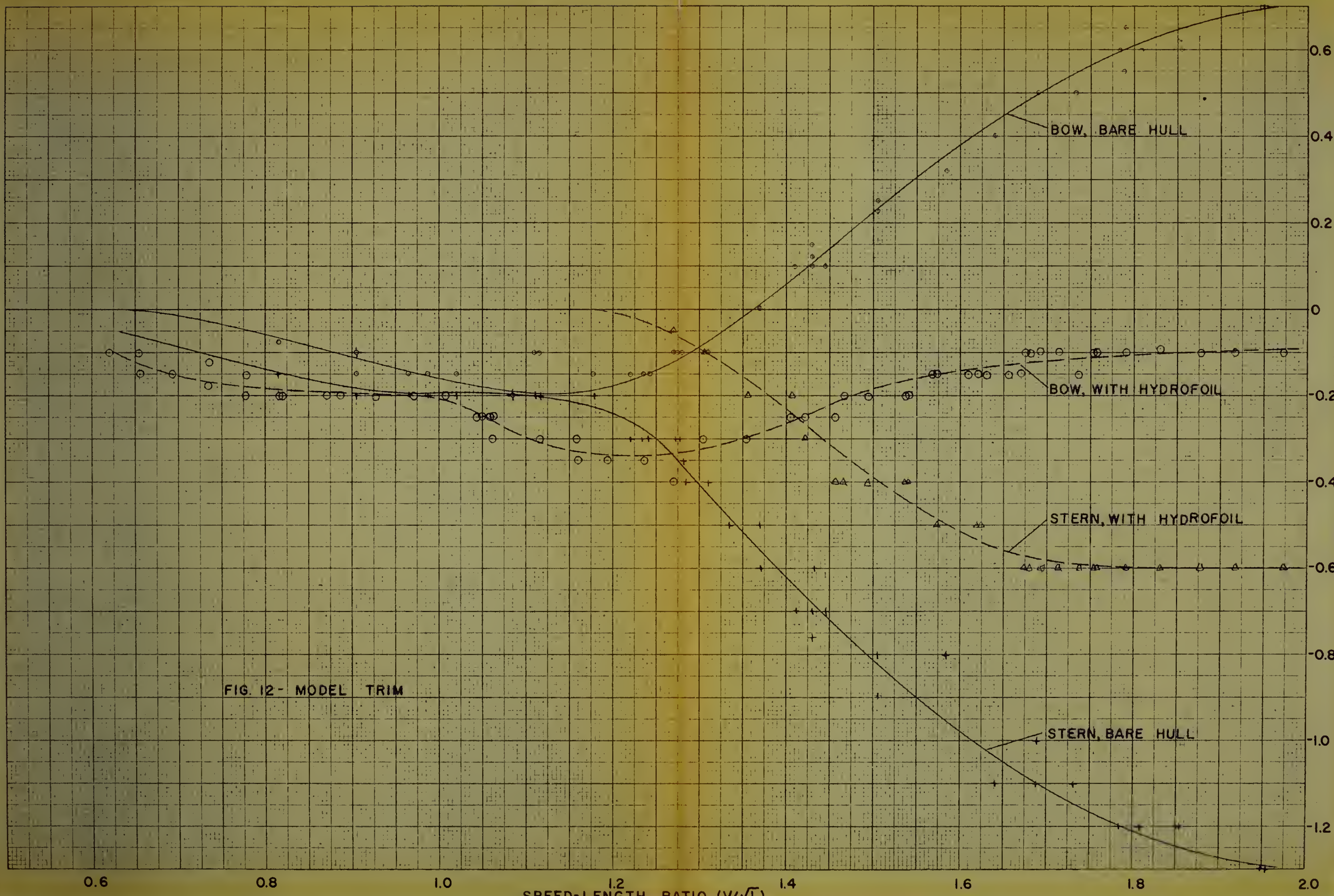


FIG. 12 - MODEL TRIM

On inspection of Figure 11 it is seen that the increased resistance due to the hydrofoil and strut is much greater at the lower speed length ratios than at the higher speed length ratios. Since the drag of the hydrofoil and the strut is a function of the coefficient of lift, angle of attack, and the wetted surface of the hydrofoil and the strut; the increase drag or resistance of the appendages should remain approximately constant over any speed range. Therefore some unknown factor must have been affecting the measured resistance. On investigation of resistance data for airfoil sections it was found in Figure 5.1 of reference (2) that the profile drag of an airfoil section operating below a Reynolds Number of 5×10^5 there is a transition from a relatively low profile drag to a high profile drag due to the effect of laminar flow separation. According to reference (5) there is no apparent scale effect on induced drag or lift.

A calculation on the model airfoil section (hydrofoil) shows that over the range of testing the model, the hydrofoil was operating at a Reynolds Number of 10^4. It is very possible then that the hydrofoil was operating in this transitional range of profile drag and the model tests would give incorrect full scale results.

In order to investigate the possibilities of this unrealistic effect of laminar flow separation it was decided to try a second approach which would, if possible, eliminate this effect.

VI. TEST METHOD TO ELIMINATE LAMINAR FLOW SEPARATION EFFECT.

In this second approach the model was run without the

hydrofoil attached but in a controlled trim condition to match the trim produced when the hydrofoil was installed. The resistance of the model was measured over the range of speed length ratios of .70 to 1.95. This resistance was then expanded to full scale resistance. The water velocity over the hydrofoil was measured and the total resistance of the hydrofoil and the strut was calculated utilizing the lift force measured, the angle of attack, and data from NACA reports as given in reference (1) for the full scale ship. The two resistances were added giving the total resistance of the ship with the hydrofoil attached in the controlled trim condition. This new calculated resistance was then compared with the expanded bare hull resistance.

VII. DETERMINATION OF SHIP RESISTANCE FROM MODEL TEST DATA AND CALCULATED HYDROFOIL DATA.

In order to eliminate the possibility of laminar flow separation influence on the hydrofoil the following procedure was used:

1. The model was tested without hydrofoil attached but in a trim condition matching that of the model with hydrofoil installed. This was done utilizing the system of weights and pulley previously described. It was not possible to match the trim using weights alone and a shift of ballast in the model in combination with the weights over the pulley was used in order to correctly match the trim of the model with the hydrofoil attached. In determining the lift force necessary to match trims the moment due to the shift in ballast was added or subtracted to the weight over the pulley depending on the required shift

of ballast.

2. A wake survey was made spanwise along the hydrofoil at the center of the chord to determine the water velocity past the hydrofoil. The wake survey apparatus is shown in Figures 13 and 14. Figure 15 shows the test calibration curve and Figure 16 shows the corresponding water velocity vs head from the calibration curve. Utilizing Figure 16 the water velocity over the hydrofoil was determined for seven points along the hydrofoil at two model speeds. The seven points were averaged giving an average water velocity over the hydrofoil at the two model speeds tested. A wake fraction for each model speed tested was calculated. Assuming a straight line function between the two speeds tested a curve of wake fraction vs model speed was plotted in Figure 17.

3. From the total lift force necessary to match trims and the water velocity over the foil as determined from the wake fraction of the hydrofoil, the cofficient of lift was calculated and plotted in Figure 18.

4. The C_t of the model was calculated. Since the weight used to change trim was in effect changing the displacement of the model a corrected wetted surface was calculated based on the relationship from reference (3): $W.S. = K\sqrt{\Delta L}$. This change in wetted surface is plotted in Figure 19 and was used in the calculation of the C_T' of the model corrected for wetted surface change due to the displacement change. The corrected C_T' is plotted in Figure 20.

5. By standard model test procedure the C_T' of the ship was calculated by expansion of the corrected model C_T' .

FIG. 13- PITOT TUBE INSTALLATION

FIG. 14 - PITOT TUBE INSTALLATION SHOWING PULLEY AND WEIGHTS TO DUPLICATE MODEL TRIM.

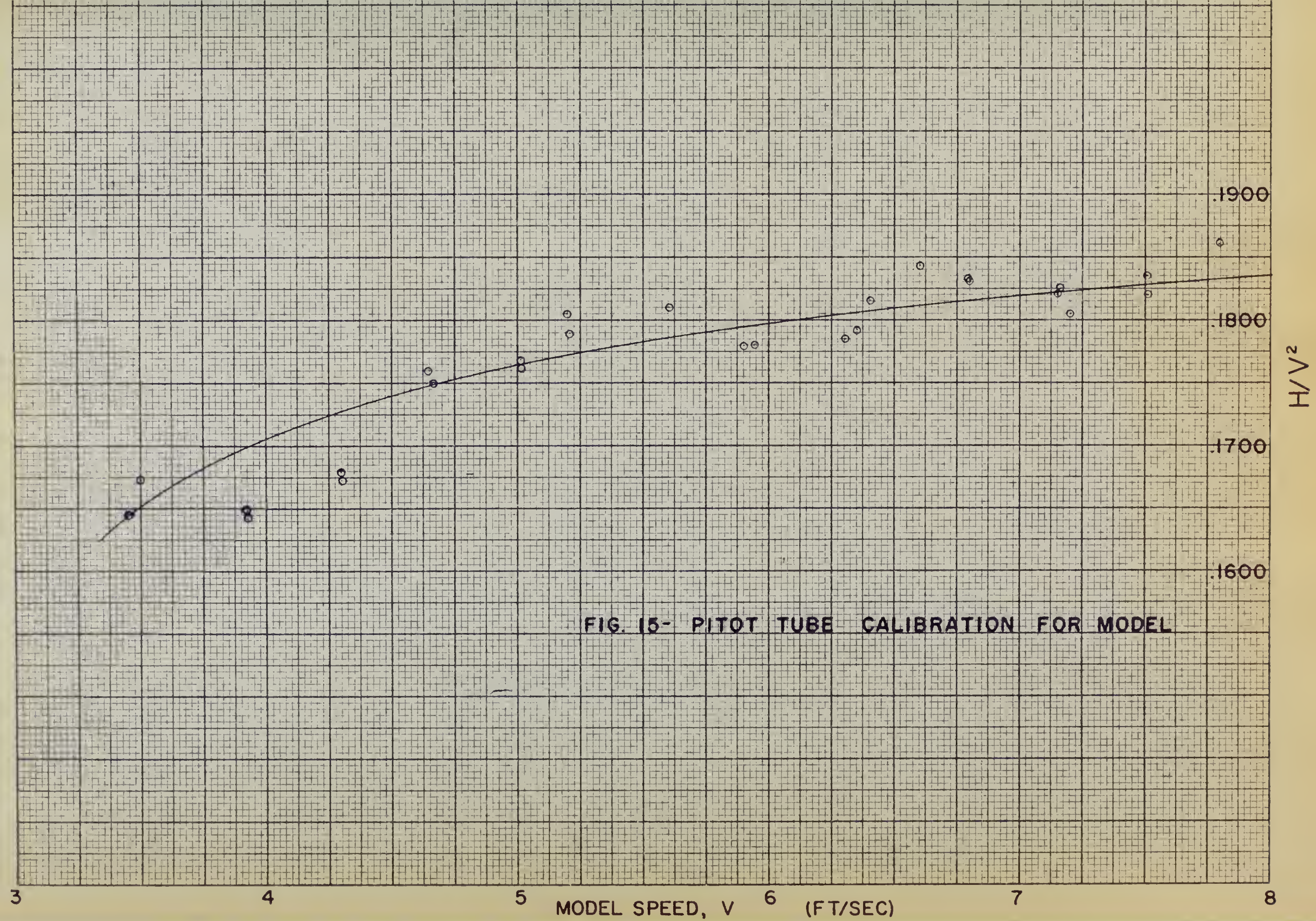


FIG. 15- PITOT TUBE CALIBRATION FOR MODEL

FIG. 16

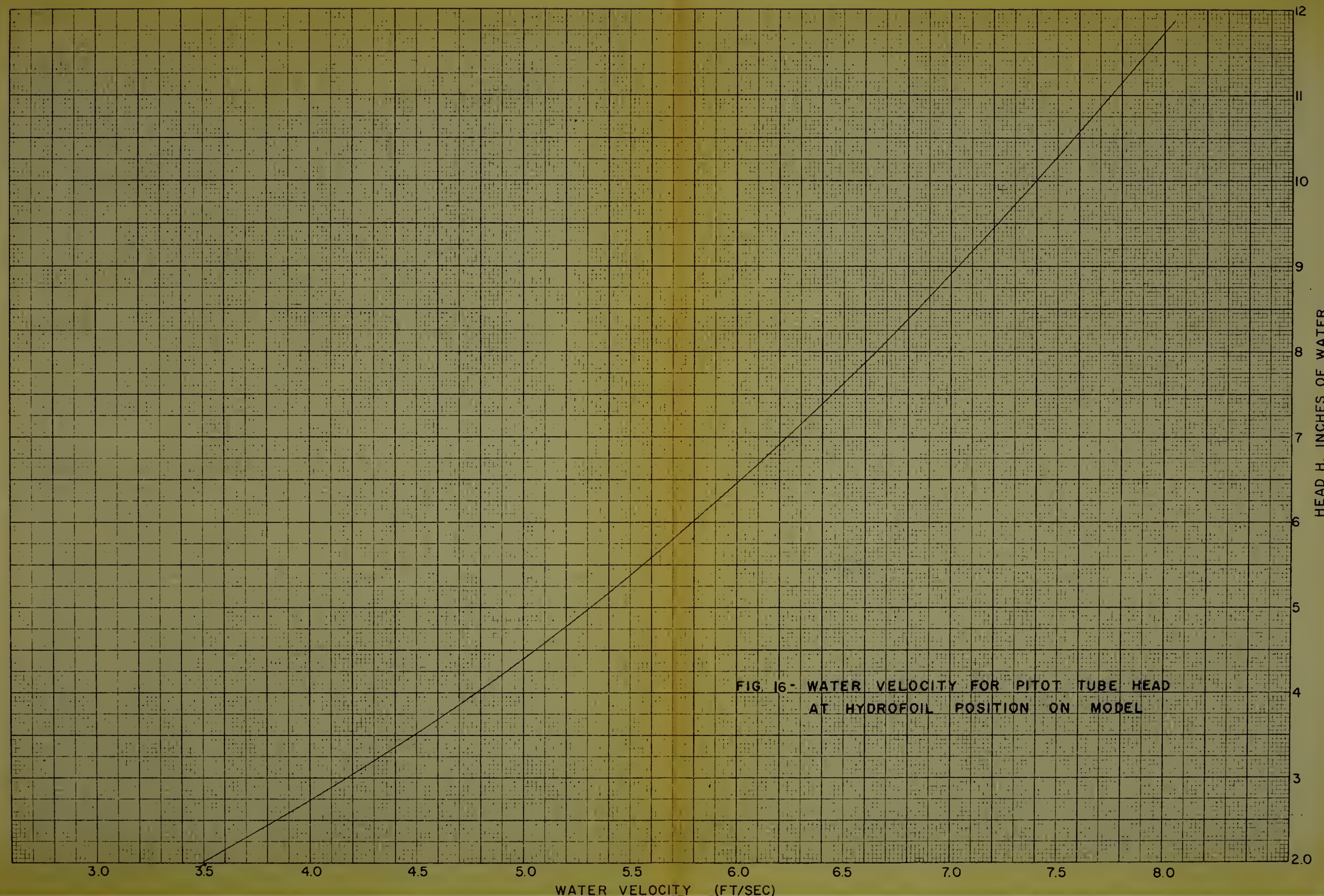


FIG. 16 - WATER VELOCITY FOR PITOT TUBE HEAD
AT HYDROFOIL POSITION ON MODEL
HEAD H, INCHES OF WATER
2.0
3
4
5
6
7
8
9
10
11
12
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
WATER VELOCITY (FT/SEC)

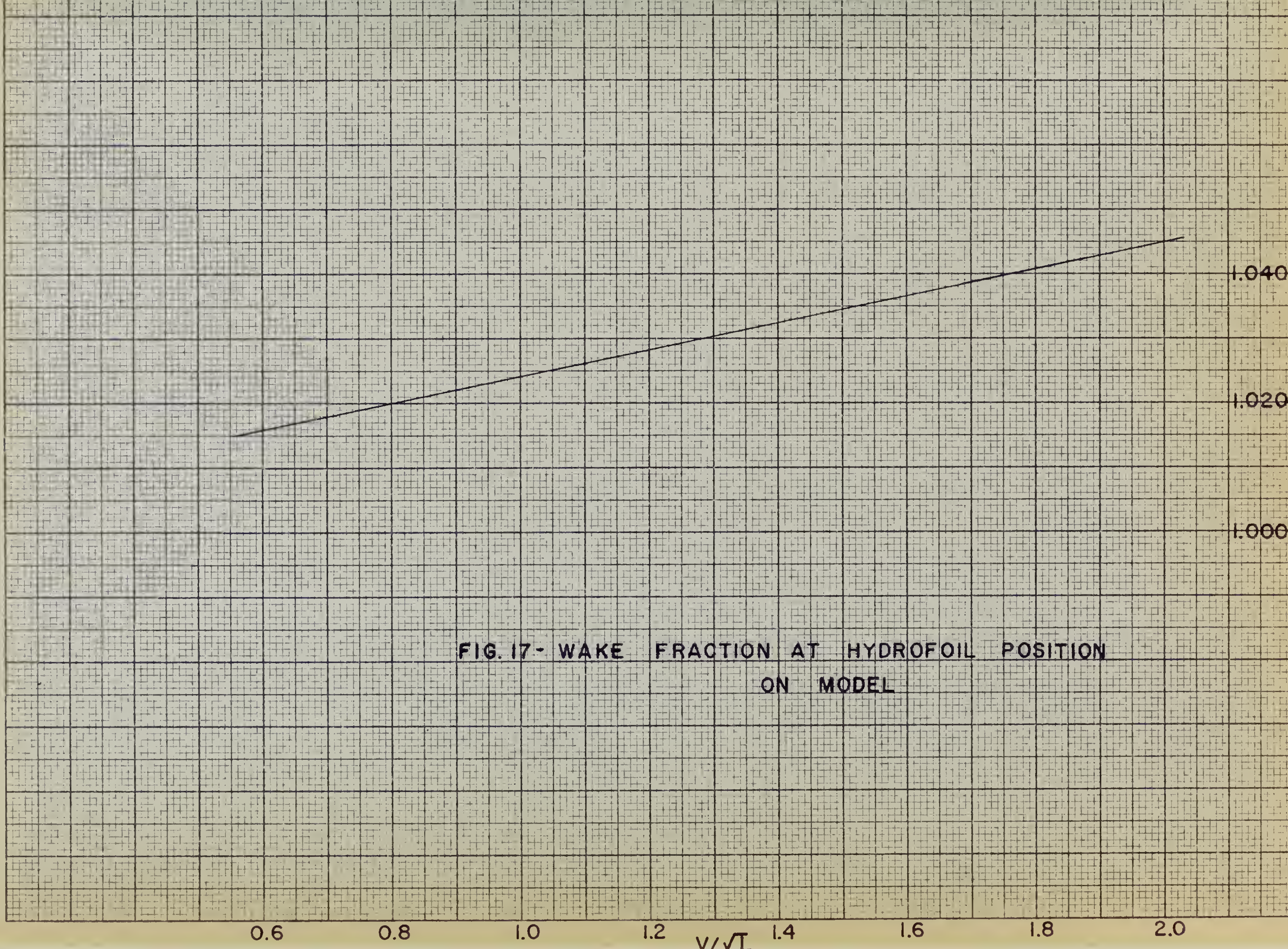


FIG. 17 - WAKE FRACTION AT HYDROFOIL POSITION ON MODEL

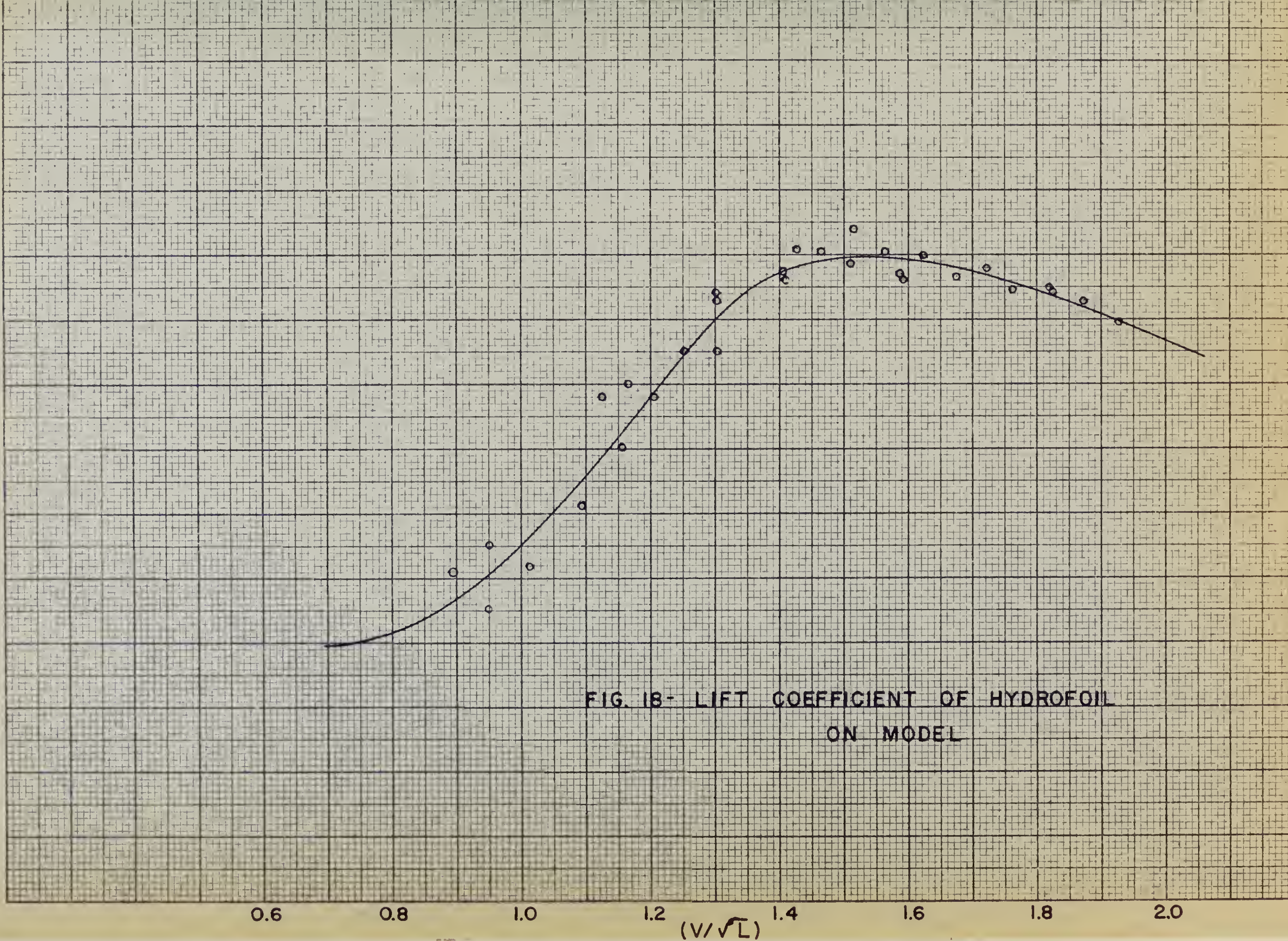


FIG. 18 - LIFT COEFFICIENT OF HYDROFOIL
ON MODEL

FIG. 19

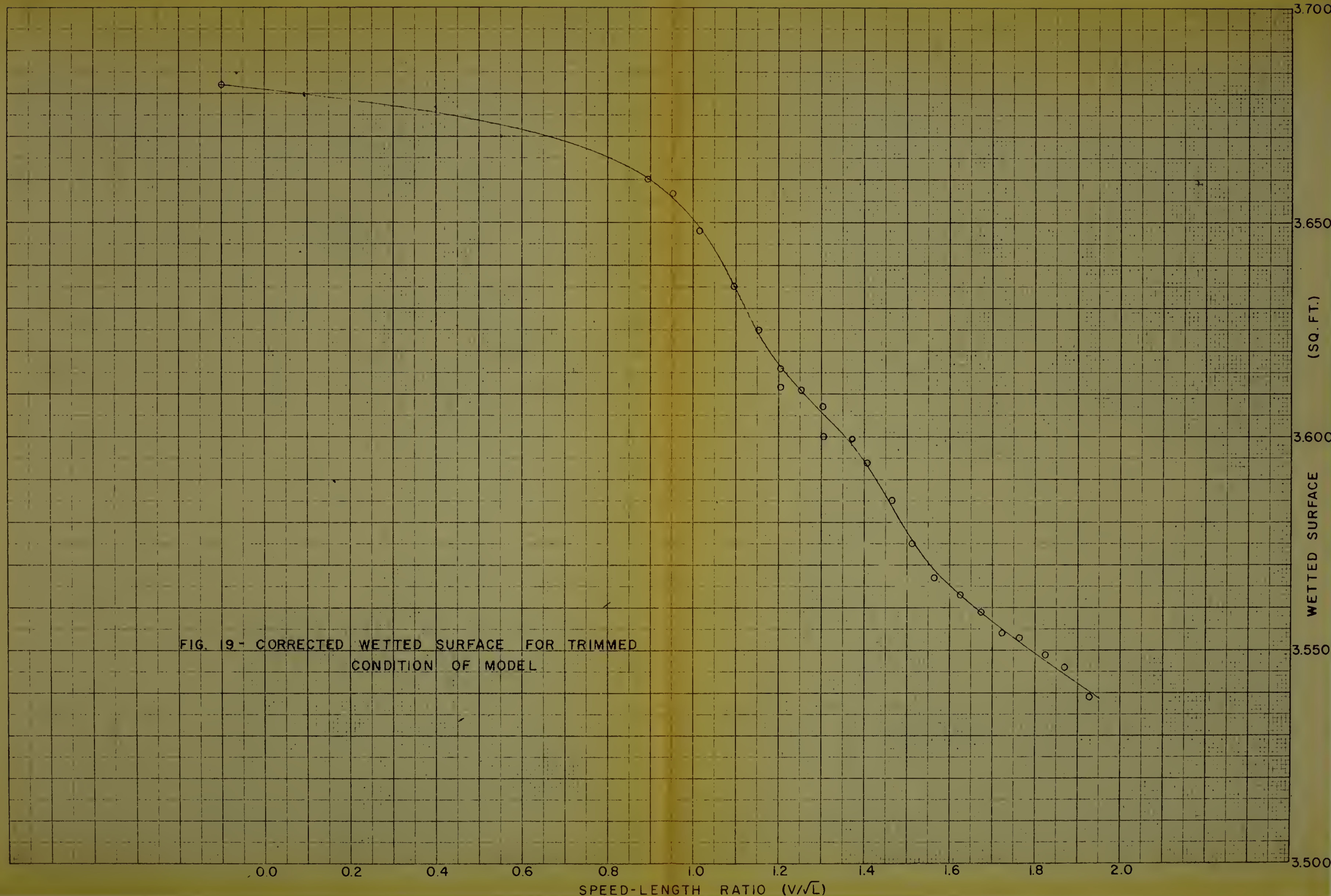


FIG. 19 - CORRECTED WETTED SURFACE FOR TRIMMED CONDITION OF MODEL

FIG. 20

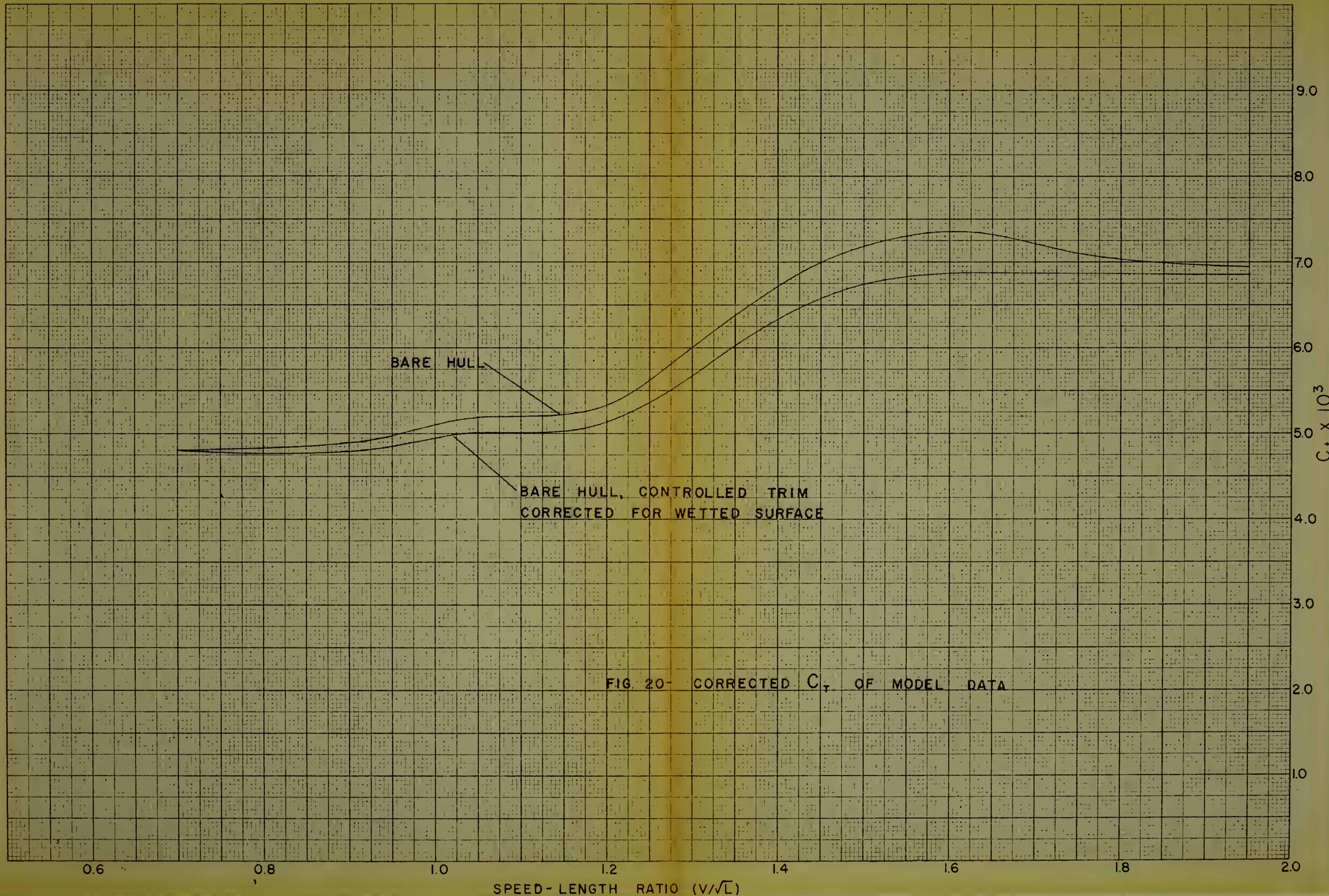


FIG. 20- CORRECTED C_T OF MODEL DATA

6. The calculated coefficient of lift was utilized in calculating the total lift of the full scale hydrofoil.

7. The total resistance of the ship bare hull in controlled trim was calculated utilizing the corrected ship C_T'. A correction was again made for the change in wetted surface due to the apparent change in displacement caused by the total lift force of the full scale hydrofoil.

8. From reference (1) the profile drag coefficient of the hydrofoil section NACA 63210 was determined.

9. By using the C_L as determined under part 3 and using reference (2) an induced drag coefficient was calculated. A correction was made for finite span.

10. A profile drag coefficient was determined for the strut using reference (1) for NACA 63018. To add this coefficient to the drag coefficient of the hydrofoil a simple area ratio expansion was used.

11. The total drag coefficient of the appendages was determined by adding the profile drag coefficient of the hydrofoil, the induced drag coefficient of the hydrofoil, and the proportioned profile drag coefficient of the strut.

12. From the total drag coefficient of the appendages and the water velocity over the foil as determined by the wake survey the total resistance of the appendages was calculated.

13. The total ship resistance in the controlled trim condition was determined by adding the calculated ship appendage resistance to the resistance of the ship bare hull in the controlled trim condition.

VIII. FINAL COMPARISON OF TESTS

Ship Ⓒ was calculated for the three test conditions:

1. Ship expanded from model tests bare hull.
2. Ship expanded from model tests with hydrofoil attached.
3. Ship expanded from model tests with controlled trim and calculated hydrofoil drag.

These results are plotted in Figure 21.

DISCUSSION OF RESULTS

The results of the test are plotted as © versus $V/\sqrt{L}$ in Figure 21. This presentation was selected due to the variation of wetted surface of the ship when the lifting force is acting. © eliminates the use of wetted surface in a resistance comparison.

The curve of © for the ship with hydrofoil expanded from model results shows that the test data at low Reynolds Number is very inaccurate in the speed length ratios from .70 to 1.45 when compared to any of the other curves. It is felt that this inaccuracy is due to the laminar flow separation when operating at low Reynolds Numbers. At the design speed length ratio of 1.45 the curve of the ship with hydrofoil approaches very nearly the curve of the ship bare hull controlled trim with calculated hydrofoil drag, but both curves are still above the ship bare hull curve.

From a speed length ratio of 1.45 to 1.95 there is no apparent explanation of the results obtained as shown by these curves.

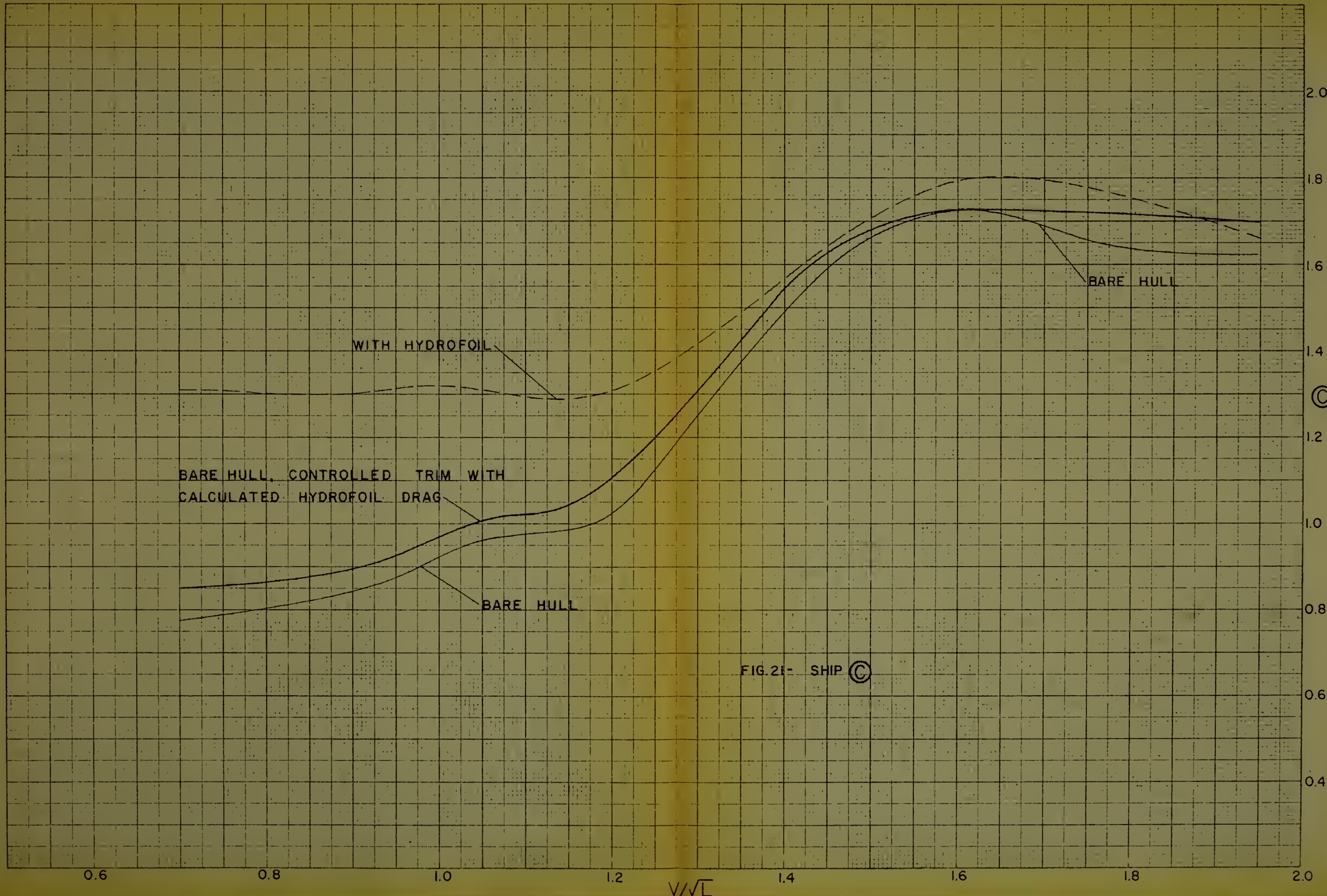
In the range of speed length ratios of 1.45 to 1.60 the curves of ship with hydrofoil and ship bare hull controlled trim again diverge, with the controlled trim curve becoming tangent to the bare hull curve while the curve of the ship with hydrofoil becomes a maximum at 1.65.

In the range of speed length ratios of 1.65 to 1.88 the curves of ship with hydrofoil and ship in controlled trim again converge and cross at the speed length ratio of 1.88. An explanation for the range of speed length ratios above 1.65 could be

that there is now some effective interaction of the hull and the hydrofoil which increases the effectiveness of this arrangement, i.e. a reduction in drag of the hydrofoil for a given lift.

By extrapolation of the curves of bare hull with hydrofoil attached to an approximate speed length ratio of 2.00 the curves would intersect showing that the hydrofoil might be effective above the speed length ratio of 2.00.

FIG. 21



WITH HYDROFOIL
BARE HULL, CONTROLLED TRIM WITH
CALCULATED HYDROFOIL DRAG
BARE HULL
BARE HULL
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
V/√L

FIG. 21 - SHIP ©

CONCLUSIONS

The hydrofoil installation as tested offers no advantage over the bare hull. The point of tangency at $V/\sqrt{L}$ of 1.60 and the possibility of the curves crossing at $V/\sqrt{L}$ of 2.00 offers some encouragement that a change in design of the installation might lead to the desired improvement.

The drag effect at low Reynolds Number as shown in the lower $V/\sqrt{L}$ range points up one very important point: hydrofoil tests should be made to as large a scale as possible to reduce the very large increase in profile drag found below a Reynolds Number of about 5×10^5. The lack of information available at this low Reynolds Number range makes small scale model testing of this type inaccurate and difficult. Because of this it offers a wide field for further study.

REFERENCES

(1) " Theory of Wing Sections", by I.H. Abbott and A.E. von Doenhoff, 1949. Pages 516, 517, and 533.

(2) "Aerodynamic Drag", by S.F. Hoerner, 1951. Chap. V, page 60; and Chap. VI.

(3) "The Speed and Power of Ships", by D.W. Taylor, Second Revision 1943. Page 23.

(4) "The Prediction of the Effective Horsepower of Ships by Methods in Use at The David Taylor Model Basin", DTMB Report No. 576, by M. Gertler, 1947.

(5) "Aerodynamic Theory", Vol. III, by Durand, 1935. Page 330.

APPENDIX

MODEL DATA

Model Number 393 built by Stevens Institute of Technology.

SHIP:

Length Load Waterline-	342.5 feet
Beam-	35.9 feet
Draft-	12.7 feet
Displacement (Salt Water)-	2314.0 tons
Wetted Surface-	14,154.0 sq.ft.
Block Cofficient-	.5174
Displacement/Length Ratio-	57.6
Beam/Draft Ratio-	2.82
Design Speed/Length Ratio-	1.73

MODEL:

Length Load Waterline-	5.524 feet
Lambda Ratio-	62.0
Wetted Surface-	3.682 sq.ft.
Trim-	None.
Displacement (fresh water)	21.17 pounds
Measured freeboard aft forecastle break	2 .17 inches
Length of model run (bare hull only)	35.23 feet
Length of model run	35.00 feet
Dynamometer setting	7.3
Towing strut pivot below top of towing bracket	2.5 inches

Trim gages located at fore and aft perpendiculars

SAMPLE CALCULATIONS

Sample calculations and sample test data results will be shown for a speed length ratio of 1.45 where possible. This speed length ratio was chosen as a design point corresponding to a ship speed of 26.83 knots and a model speed of 5.74 feet per second.

BARE HULL TEST RESULTS

ΔT sec	V ft/sec	V kts	$\frac{V}{\sqrt{L}}$	V^2	scale read.	wt corr.	pan wt	R_T	R_T/V^2	trim * fwd	trim * aft
6.13	5.75	3.40	1.447	33.06	5.5	.151	.64	.791	.0239	-1	+ 3.5

* Forward trim measurement in tenths of inches and after trim measurements in fifths of inches.

MODEL BARE HULL C_T CALCULATIONS

$T = 73.6\ °F$ WS = 3.68" Sq. ft. $a = 1.426 \rho S$

$\rho = 1.935$ $C_T = \frac{R_T}{2.852/2\ SV_2^2}$ $a = 10.1614$

$\nu = 1.0070$

V knots	V^2	$a\ V^2$	R_T	$C_T \times 10^3$
3.40	11.560	.1175	.791	6.732

BARE HULL MODEL WITH SIMULATED LIFTING APPARATUS TEST RESULTS

ΔT sec	V ft/sec	V kts	$\frac{V}{\sqrt{L}}$	V^2	scale read	wt corr.	pan wt	R_T	R_T/V^2	trim fwd	trim aft
6.01	5.86	3.47	1.48	34.34	4.3	.1380	.64	.7780	.0227	+ 3	+11/2

DETERMINATION OF SIZE OF HYDROFOIL

$L = \rho/2\ S\ V^2\ C_L$

Optimum model lift = 1.5 pounds

$\rho = 1.9352$ at 74° F

V = 5.75 feet per second

$C_L = .80$ assumed

$S = \frac{L}{\rho/2\ V^2\ C_L} = .0586$ square feet

span = 6.00 inches

chord = $\frac{.0586 \times 144}{6} = 1.41$ inches

required hydrofoil = 1.41 x 6.00 inches

DETERMINATION OF OPTIMUM ANGLE OF ATTACK

Foil apparatus in aft low position, $\alpha = + 4°$

ΔT sec	V ft/sec	V kts	$\frac{V}{\sqrt{L}}$	V^2	scale read.	wt corr.	pan wt	R_T	R_T/V^2	trim fwd	trim aft
5.34	6.56	3.88	1.65	43.10	4.2	.137	1.08	1.217	.0282	+ 1.5	+1.5

DETERMINATION OF FORE AND AFT AND VERTICAL LOCATION OF HYDROFOIL

Position	R_T/V^2 bare hull, foil and strut	R_T/V^2 bare hull and strut	R_T/V^2 bare hull	R_T/V^2 strut ONLY	R_T/V^2 bare hull and foil
aft low	.0271	.0268	.0260	.0008	.0263

DETERMINATION OF MODEL RESISTANCE AND TRIM WITH HYDROFOIL IN FINAL SELECTED POSITION

Test data

Δ T sec	V ft/sec	V kts	$V/\sqrt{L}$	V^2	scale read.	wt corr.	pan wt	R_t	R_T/V^2	trim fwd	trim aft
6.05	5.78	3.42	1.46	33.49	4.9	.144	.71	.854	.0255	+ 2	+ 2

Calculated data

$T = 80.5\ °\ F$

$\rho = 1.93345$

$WS = 3.682$ Sq Ft

$$C_T = \frac{R_T}{2.852\ \rho/2\ SV^2}$$

$a = 1.462\ \rho\ S$

$a = 10.15164$

V kts	V^2	$a\ V^2$	R_T	C_T
3.422	11.710	.1188	.854	7.189

DETERMINATION OF MODEL RESISTANCE IN BARE HULL CONTROLLED TRIM CONDITION

ΔT sec	V ft/sec	V kts	$\frac{V}{\sqrt{L}}$	V^2	scale read.	wt corr.	pan wt	R_T	R_T/V^2	trim fwd	trim aft	lift wt lbs	ballast shift
6.02	5.81	3.44	1.46	33.76	4.8	1.430	.63	.7730	.0229	+3.75	+1.75	1.10	1.25 fwd

DETERMINATION OF REQUIRED HYDROFOIL L IFT FORCE TO MAINTAIN MODEL IN BARE HULL CONTROLLED TRIM CONDITION

T = 80° F S foil = .0015 sq ft Ballast wt = 1.84 lb

ρ = 1.9336 $\rho/2$ S = .05327 Mom arm = 39.39 in.

V ft/sec	V^2	$\frac{V}{\sqrt{L}}$	Lift wt	ballast shift	moment	addition to lift wt	total lift
5.81	33.76	1.464	1.10	1.25 fwd	+ 2.30	.058	1.158

DETERMINATION OF WATER VELOCITY AT HYDROFOIL

Pitot tube test data

position	T sec	V ft/sec	total head in: inital	total head in: final	total head in: Diff	static head in: inital	static head in: final	static head in: Diff	Vel head	H/V^2
Cal	4.93	7.10	8.15	12.25	4.10	8.00	2.90	5.10	9.20	.1820
4	5.00	7.00	8.40	12.65	4.25	8.40	2.95	5.45	9.70	----

WAKE RAKE CALCULATIONS FROM FAIRED H/V^2 VS V CURVE 15 AND H VS V CURVE 16.

$$V_w = (1 - w)\ V_m$$

V ft/sec	V^2	H/V^2 fig 15	H
7.00	49.00	.1820	8.92

station	H	V_w fig 16	V_m	1-w
4	9.70	7.29	7.00	1.041

CALCULATION OF C_L FOR HYDROFOIL ON MODEL

$T = 80°F$

$\rho = 1.9336$

$S = 7.935$ sq in = .0551 sq ft

$\rho/2\ S = .05327$

$$C_L = \frac{\text{lift}}{\rho/2\ S\ V_w^2}$$

V_m ft/sec	(1-w)	V_w FT/sec	V_w^2	$\frac{V}{\sqrt{L}}$	total lift	$\rho/2SV_w^2$	C_L
7.00	1.040	7.280	52.998	1.763	1.617	2.823	.573

CALCULATION OF C_T OF THE MODEL I N CONTROLLED TRIM CONDITION

$T = 80°F$

$\rho = 1.9336$

$S = 3.682$ Sq ft

$a = 1.426\,\rho\,S$

$a = 10.15243$

$$C_T = \frac{R_T}{a\ V^2}$$

$$\frac{1}{L} = .42548$$

V_m kts	V_m^2	$a\ V^2 \times 10^{-3}$	R_T	$C_T \times 10^3$	$\frac{V}{\sqrt{L}}$
3.440	11.834	.1201	.7730	6.436	1.464

CALCULATION OF CORRECTED WETTED SURFACE FOR MODEL IN CONTROLLED TRIM CONDITION

Model disp. = 21.17 pounds

Model length = 5.524 Feet

$W.\ S. = K\sqrt{\Delta L} = K'\sqrt{\Delta}$

$K' = .8002433$

V_m kts	$V/\sqrt{L}$	lift wt	new disp.	$\sqrt{\text{disp. new}}$	wetted surface WS'
3.44	1.464	1.10	20.07	4.48	3.585

CALCULATION OF C_T' FROM C_T OF MODEL IN CONTROLLED TRIM CONDITION

CORRECTION DUE TO CHANGE IN DISPLACEMENT

Model wetted surface = 3.682 sq ft

$\frac{V}{L}$	$C_T \times 10^3$ curve	W S' curve	$\frac{W\ S}{W\ S'}$	C_T'
1.45	6.42	3.586	1.0268	6.59

CALCULATION OF C_T' SHIP FROM C_T' MODEL IN CONTROLLED TRIM

$T_m = 80°F$ $T_s = 59°\ F$ (salt water)

$\nu = .92969$ $\nu = 1.2817$

$\frac{V}{\sqrt{L}}$	model $C_T' \times 10^3$	model $C_f \times 10^3$	$C_r \times 10^3$	model $R_e \times 10^{-6}$	ship $C_f \times 10^3$	ship $C_T' \times 10^3$	ship $R_e \times 10^{-8}$
1.45	6.59	3.519	3.071	3.420	1.496	4.567	12.11

CALCULATION OF TOTAL LIFT OF FULL SCALE HYDROFOIL

$1/2\ \rho\ S = 210.798$

$V/\sqrt{L}$	V ft/sec	1 - w	V_w	V_w^2	$\frac{1}{2}\ S\ V^2$	C_L	lbs Lift
1.45	45.32	1.033	46.82	2192.11	462.092	.594	274,483

CALCULATION OF TOTAL RESISTANCE OF SHIP BARE HULL IN CONTROLLED TRIM CONDITION

original Δ = 2276.7   original W.S. = 14,154

$\rho/2$ ship = .99525

new Δ LBS	$\sqrt{\Delta \text{ new}}$	$\frac{\sqrt{\Delta_{new}}}{\sqrt{\Delta_{orig.}}}$	WS'	$\frac{1}{2}\rho WS'$	V^2	$\frac{1}{2}\rho WS'\ V^2$	C_T'	RT lbs
4,908,000	2215.5	.973	13.772	13.706	2053.9	28,151,000	4.567	128,566

CALCULATION OF APPENDAGE RESISTANCE

1. Determination of effective aspect ratio from reference 2

Aspect ratio $A = \frac{b^2}{S}$

b = span = 6.04 inches

S = foil area = 7.935 sq in by planimeter

tip correction = - .04 (page 76 par 2 reference 2)

$$A_e = \frac{b^2}{S} - .40 \quad = \frac{6.04^2}{7.935} - .40$$

$$A_e = 4.198$$

$$C_{Di} = \frac{C_L^2}{\pi A_e}$$

2. Determination of strut profile drag coefficient

Area strut = 2.112 square inches (planimeter)

Area foil = 7.935 square inches (planimeter)

Strut NACA 63018 section profile drag coefficient is .0058 at 0° angle of attack from reference 1.

$$\text{profile drag coefficient corrected} = .0058 \times \frac{2.112}{7.935} = .0015$$

$$\frac{1}{\pi A_e} = .07583 \qquad \rho/2\ S = 210.798$$

$V/\sqrt{L}$	V	$1-w$	V_w	V_w^2	C_L	C_L^2
1.45	45.32	1.033	46.82	2192.11	.594	.3528

foil C_{Di}	foil C_{Dp}	foil C_{DT}	strut C_{Dp}	C_{DT}	$\rho/2\ S\ V_w^2$	R_T app.
.0268	.0078	.0346	.0015	.0361	462,092	16,682

TO CALCULATE TOTAL SHIP RESISTANCE AND © IN CONTROLLED TRIM CONDITION

$\rho / 2\ S = 14{,}086.77$ $\qquad \dfrac{W.S. \times 1000}{Vol^{2/3}\ 8\pi} = .3243945$

$$© = \frac{C_T \times W.S. \times 1000}{Vol^{2/3}\ 8\ \pi}$$

R_T hull	R_T APPEN.	R_T total	V^2 ft/sec	$\rho/2\ S\ V^2$	C_T	©
128,566	16,682	145,248	2053.9	28,937,813	5.019	1.628

 Nelson
An investigation of the change in resistance of a destroyer type hull utilizing a hydrofoil to reduce excessive trim.

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